FUEL EFFICIENCY BOOKLET 19

Process plant insulation and fuel efficiency

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

Cover photograph courtesy of Shell UK

CONTENTS

CONTENTS

INTRODUCTION

1 INTRODUCTION

This booklet is concerned with thermal insulation in process plant. 'Process plant' includes pipework, ducts, equipment and storage vessels. Practical advice on process plant insulation is given and is intended for use by experienced process plant personnel and as training material.

Thermal insulation works by providing a thermal barrier which slows down the rate of heat transfer. There are many reasons for insulating process plant, the most important of which is cost saving. Cost savings arise because thermal insulation can minimise heat losses and hence reduce the energy input needed to maintain the temperature of, for example, a process fluid in a vessel. The other main reasons for insulation are:

- to reduce heat gain;
- to provide condensation control;
- to provide frost protection;
- to provide pipe protection (either personnel protection, corrosion protection or isolation of hot pipes);
- to control process temperatures;
- to provide fire protection;
- to provide acoustic insulation.

Several of the reasons for thermal insulation listed above are associated with process requirements. Safety also features as a reason for thermal insulation in hazardous environments or where personnel are likely to come into contact with hot or very cold surfaces.

In this booklet, the principal reasons for insulating process plant are discussed, and information is given on the different types of insulation and their properties. Extensive data are presented in tabulated form on the recommended thicknesses of insulation for optimum cost/benefit performance, and energy and costs savings are discussed qualitatively.

A number of important practical aspects of thermal insulation, such as finishes, have to be taken into account, and these are discussed in the context of general good practice.

Specific items of process plant and equipment necessitate individual attention when it comes to specifying thermal insulation. One section describes, with examples, some of the features which must be taken into account.

This booklet is intended as a brief guide to thermal insulation, and therefore references are made throughout to the extensive documentation available from the insulation industry and the British Standards Institution (BSI).

It is recommended that this booklet is read in conjunction with Fuel Efficiency Booklet 8 - *The Economic Thickness of Insulation for Hot Pipes* - which gives more details on pipe insulation.

2 REASONS FOR INSULATION

Cost saving

The economic benefits to users of thermal insulation can vary considerably, depending mainly on whether the insulation is fitted after the plant has been constructed, or is taken into account during the plant design stage and incorporated during construction. Maximum benefits will be achieved by building insulation into a design. Early identification of the need for thermal insulation can, for example, reduce the size of steam-raising plant or refrigeration capacity, and consequently the associated plant rooms and supporting equipment. In cases where plant capacity increases are necessary,

REASONS FOR INSULATION

retrofitting insulation may obviate the need for additional plant.

The type of financial exercise, or cost/benefit analysis, used to appraise the economics of thermal insulation will vary from company to company, and it is outside the scope of this booklet to detail such analyses. In most cases involving insulation, a simple payback calculation may be used to compare options, where the net energy savings are compared with the installed cost of the insulation. Typically, a payback period of two years, i.e. the net energy cost saving pays for the installation in two years, would be considered reasonable by many companies. The payback period generally increases with the thickness of insulation, hence the use of the term economic thickness in much tabulated data on the recommended thickness of insulation (for example in BS 5422: 1990).

When determining the economics of particular insulation, the installation cost and the cost of the finishing materials should always be included. High performance insulation, which may require a significantly lower thickness than some of the more conventional materials, will need much less covering, or finishing, than the thicker alternatives. This can result in significant savings when the total costs for insulation are compared. (See Section 7 for details of different types of finishes.)

Process requirements

Process requirements for insulation are mainly to ensure that steam, hot water, hot gases, or cold liquids and gases are delivered from a central source to the point of use in an acceptable condition. The selection and degree of insulation in these cases is not decided solely on the economic grounds.

There are many different processes, each requiring different temperatures and conditions, and the design of the required insulation will be unique in each case. There are, however, a number of common principles which should be considered.

The heat loss from a length of pipe will depend on the temperature of the fluid being carried and that of the surrounding medium. The amount of insulation will influence the heat loss, but the rate of heat loss will be constant when the internal and external conditions are constant. A change in these conditions, for example an increase or reduction in the flow rate inside the pipe, will change the rate of heat loss, and this should be taken into account in variable flow processes.

Where flows are reduced significantly, i.e. during low process loads at specific times, much lower delivery temperatures than normal may result. Lower heat losses arising from a lower bulk fluid temperature may lessen the effect, but if process conditions necessitate a constant delivery temperature, a higher source fluid temperature will still be required.

The assessment of acceptable levels of insulation can be divided into two stages:

- the determination of the heat loss from the external surface;
- the effect this heat loss has on the conditions of the fluid in the pipe.

The first stage is facilitated by tabulated or graphical data of the form presented in this booklet and in Fuel Efficiency Booklet 8 - *The Economic Thickness of Insulation for Hot Pipes* - where data for the most common situations are given.

TYPES OF INSULATION

The second stage necessitates a study of the effect any heat loss may have on the properties of the fluid in the pipe. For example, if steam is being transported, the reduction in temperature may lead to condensation which might necessitate the use of steam traps; where it is required to reduce condensation to a minimum, the rate of flow should be kept as close as possible to the design figure and the level of thermal insulation increased.

A special case arises where condensation must be avoided to prevent corrosion or undesirable emissions. For boilers there is a conflict between the need to reduce exit temperatures to the minimum possible, in order to extract the maximum amount of energy, and the need to keep temperatures above the safe level (acid dewpoint of the flue gases) to avoid corrosion. When a boiler is operating on light loads, this problem can be aggravated, and is a particularly important consideration for oil-fired boilers. Boiler flues therefore need to be insulated to prevent the exit gases falling below their 'acid dewpoint'.

Much of the discussion so far has concentrated on pipes and ducts; however, many other components liable to contribute to heat losses exist in a distribution system, and these all need to be taken into account. For example, uninsulated valves and flanges can account for up to 20% of the heat lost from a distribution system. Section 9 of this booklet discusses vessels, flanges, valves and other such components, each requiring individual attention.

Safety

In many cases, thermal insulation is essential from a safety point of view and its use is not primarily concerned with energy cost savings. There are two main aspects of safety involving the use of insulation:

- it can protect plant operatives from coming into contact with very hot or very cold surfaces;
- it can reduce the risk of fire or explosion due to the proximity of combustible gases or vapours to hot surfaces.

Insulation can also make an important contribution to creating comfortable conditions, especially where personnel are working close to high temperature plant.

When applying insulation for safety reasons, the criterion used to determine the thickness of the thermal insulation is the outer surface temperature, rather than the heat loss rate. Although the decision does not depend on energy costs, the cost of the insulation can be minimised by selecting the most appropriate and economic type which will give the required external surface temperature.

Other reasons

A number of other reasons exist for applying thermal insulation, some of which are:

- it can provide frost protection when pipes are likely to be exposed to low ambient temperatures;
- it can act as acoustic insulation in some situations;
- it can reduce the risk of mechanical damage to pipework and other components.

3 TYPES OF INSULATION

The range of insulation materials is large, and new products are regularly introduced to the market. In this Section the principal types and

TYPES OF INSULATION

forms of thermal insulation are briefly described.

Insulation materials are classed as either inorganic or organic. Inorganic insulants are based on the use of crystalline or amorphous siliceous/aluminous/calcium materials in fibrous, granular or powdered forms, manufactured to produce structures with a high void content. Organic insulants are based on the use of hydrocarbon polymers, which can be expanded to produce high void content structures. Both types of insulant are available in many forms, as listed below. Further information on their uses and properties can be found in Section 4.

- *Preformed*
  Preformed insulation normally takes the form of slabs, pipe sections and related shapes based on rigid structures of cellular, granular or fibrous materials. Rigid cellular plastics, and bonded natural materials such as cork, can also be preformed.
- *Flexible*
  Flexible insulation has the advantage that it can be readily formed to the shape of the component to be insulated. Textile tapes and insulation blankets, felts, mats and flexible foamed or expanded plastic materials are the most common forms of flexible insulation.
- *Loosefill*
  Loosefill insulation comprises all aggregates that can be poured or lightly packed into cavities or jackets. Perlite and vermiculite are common examples.
- *Plastic composition*
  Insulants of this type consist of dry powder, possibly with fibrous reinforcement, which is prepared for use by mixing with water. Generally heat is applied to speed up the setting process, but occasionally products need to be hardened by applying hydraulic pressure.
- *Spray-applied*
  This type of insulant is applied by spray gun and usually consists of granular, foamed or fibrous material that sticks to the surface on application. An adhesive may be included in the original mix or it may be applied simultaneously using a separate nozzle.
- *Foamed in situ*
  Cellular organic plastics can be foamed to fill a cavity by physical or chemical means.
- *Microporous insulation*
  Microporous insulant, sometimes known as silica aerogel, consists of a fine powder with microscopic pores which give the material a thermal conductivity lower than that of still air. It is available preformed or encapsulated in a fabric.
- *Reflective insulation*
  This type of insulation reflects radiant heat as opposed to reducing the rate of heat loss. Metals such as aluminium foil and thin polished stainless steel sheet are common forms of the insulant.
- *Insulating boards*
  These are rigid or semi-rigid boards, regularly with fibrous reinforcement, bonded into a compact mass.
- *Insulating bricks and allied products*
  These insulants are based on an inorganic lightweight aggregate and bonding clay, formed into rigid insulating shapes by firing at high temperature.
- *Insulating concretes*
  Insulating concretes typically consist of a lightweight porous aggregate with hydraulic

PROPERTIES OF THERMAL INSULATION

cement as the bonding agent, or a bonded or hydraulically set foam.

- *Prefabricated shapes*
  These insulating shapes are prepared from a variety of insulants for specialised applications, where the application and removal of the insulation is facilitated by using preformed insulation. Insulation covers for valves are a typical case.

4 PROPERTIES OF THERMAL INSULATION

The principal purpose of thermal insulation is to reduce heat transfer from a hot source to ambient, or from ambient to a cold process. An important property of thermal insulation is therefore its low thermal conductivity. Other requirements must also be considered to determine the insulation properties needed for each particular application; for example, the external conditions to which the insulation may be subjected are important. Some of the more important properties to be considered are listed in Section 4. In Section 4, some of the most commonly used insulation materials are listed, together with their basic properties and potential uses.

Important properties for consideration

- *Resistance to prolonged exposure*
  This is particularly important where insulation will be exposed to extreme operating temperatures and conditions, to ensure that it not only remains structurally strong but that its insulating properties are maintained.
- *Physical strength*
  This must be adequate to withstand delivery, storage, handling and application without affecting the original insulating properties.
- *Compressive strength*
  This needs to be sufficient to withstand any possible loading after installation, such as ladders etc.
- *Mechanical stability*
  Insulation must not only be able to withstand loads after installation, but must also provide the necessary resistance to vibration and be able to withstand expansion and contraction. The expansion coefficients of most insulants will differ from those of the object they are insulating.
- *Safety*
  Hazards to health during the application of insulation should be taken into account. Further details of hazards related to finishes can be found in Section 7. The fire and explosion hazards associated with insulation materials should be considered at selection, and adhesives and bonding materials used during application must also be considered as these can also be hazardous. Smoke generation potential in case of fire is important when insulation is being used in buildings, as it can hinder fire fighting and be dangerous to personnel.
- *Resistance to corrosion*
  Leaks or internal condensation can wet insulation and may weaken it. Insulation containing soluble compounds is particularly prone to corrosion. Resistance to chemicals in the proximity of the insulation, perhaps from external sources, may also be important.
- *Weight and thickness of insulation*
  In some instances, the weight of the insulation may necessitate additional supports for pipework etc. The thickness

PROPERTIES OF THERMAL INSULATION

selected will affect space requirements, and is particularly important if insulation is being retrofitted.

- *Resistance to water vapour penetration and water absorption*
  These factors are important, as water increases the thermal conductivity of the insulation, reducing its effectiveness. Fibrous and open pore structures are prone to this effect.
- *Resistance to vermin and fungus*
  In food stores and factories, insulation should be resistant to vermin and fungal growth. Finishing with non-absorbent materials should be considered.

Properties and uses of common thermal insulation materials

Fifteen of the most common thermal insulation materials are briefly described in this section, in terms of their characteristics, uses and properties. These properties are quantified in Table 1. For full data, refer to the Thermal Insulation Manufacturers and Suppliers Association Handbook (see Section 11).

- *Calcium silicate*
  Calcium silicate is widely used in industrial process plant applications where a high service temperature and good compressive strength are needed. It is also used for insulating buried district heating mains.
- *Cellular glass*
  Cellular glass is a completely impermeable material, and is used to insulate pipework and equipment in the petrochemical, gas and process industries. It can be used for insulation over a wide temperature range, including cryogenic applications. It is also ideal for insulating tank bases because of its high compressive strength.
- *Expanded nitrile rubber*
  Expanded nitrile rubber is a flexible material, which forms a closed cell integral vapour barrier. It was originally developed for condensation control on refrigeration pipework and chilled water lines, and is now widely used in Heating and Ventilation (H & V) applications.
- *Expanded polystyrene and extruded polystyrene foam*
  Expanded polystyrene and extruded polystyrene foam are also closed cell integral vapour barrier materials. They are mainly used in structural applications, such as cold-store construction.
- *Flexible polyurethane foams (filled grades)*
  These foams are open cell materials with good noise absorption properties, and are therefore used as acoustic duct lining.
- *Glass mineral wool*
  Glass wool is available in a wide range of forms, ranging from flexible rolls to rigid slabs and preformed pipe sections. It is used extensively for thermal and acoustic insulation on H & V services, as well as in industry.
- *Magnesia*
  Magnesia is a clean, inert product and consequently it is widely used in the food, pharmaceutical and cosmetics manufacturing industries, and other processes where clean environments are particularly important.
- *Melamine foam*
  Melamine foam is a very low density, open cell, CFC free, flexible material with good

PROPERTIES OF THERMAL INSULATION

thermal and acoustic insulation properties. For an organic material, it also has a high upper temperature limit.

- *Microporous silica insulation*
  Microporous insulation is widely used in storage heating systems, and for industrial high temperature insulation where better thermal performance is required than that which can be provided by fibrous insulation.
- *Phenolic foam*
  Phenolic foam offers high thermal insulation at relatively low thicknesses, and is also fairly inert. It is therefore used in H & V applications where high insulation standards are needed, but space is limited, and in industries where Class 0 fire rating and low smoke emission characteristics are required.
- *Polyethylene foam*
  Polyethylene foam is used principally in domestic applications.
- *Polyisocyanurate foam (PIR)*
  PIR is available in high strength forms and is widely used to insulate cryogenic and medium temperature pipework, and equipment in the petrochemical, gas and process industries. It is used on all types of refrigerated transport, and in buildings and building services ducting and pipework.
- *Rigid polyurethane foam (PUR)*
  PUR can be applied by in situ spray systems, and high density variants are available. It is used in medium to heavy duty refrigeration

Table 1 Properties of thermal insulation materials

Insulation	Temperature range (°C)		Thermal conductivity (W/m.K)*	Thickness range (mm)	
	minimum	maximum		minimum	maximum
Calcium silicate	-20	800	0.006	25	100
Cellular glass	-260	430	0.050	40	130
Expanded rubber	-40	116	0.036	6	32
Expanded polystyrene	-100	80	0.033	12	610
Extruded polystyrene foam	-180	75	0.027	30	100
Flexible polyurethane foams	20	105	0.048	19	100
Glass mineral wool	-160	230	0.040	19	100
Magnesia	-20	315	0.060	25	88
Melamine foam	20	220	0.040	6	250
Microporous silica insulation	-20	1050	0.025	3	75
Phenolic foam	-185	120	0.020	15	-
Polyethylene foam	-20	100	0.037	9	38
PIR	-185	140	0.023	15	-
PUR	-185	110	0.023	15	-
Rock mineral wool	-160	850	0.040	19	100

* *Note: The thermal conductivity values of most insulation materials vary with temperature. Mean values have been used in Table 1. Manufacturer's data should be consulted for full information.*

RECOMMENDED THICKNESSES OF INSULATION

applications, for minimising heat gain and condensation control. Low temperature tanks, cold stores and buildings, and refrigerated vehicles are typical application areas.

- *Rock mineral wool*
  Rock wool is available in a range of forms, from lightweight rolled products to heavy rigid slabs, including preformed pipe sections. As well as offering thermal insulation, it has good acoustic insulation and fire protection properties.

5 RECOMMENDED THICKNESSES OF INSULATION

British Standard BS 5422: 1990 - *Method for specifying thermal insulating materials on pipes, ductwork and equipment (in the temperature range -40°C to +700°C)* - contains extensive tabulated data listing recommended thicknesses of insulation for various purposes. The data considered to be most useful to plant engineers and energy managers using this booklet are reproduced in full here, together with appropriate comments on the derivation of the tables.

Note that in the tabulated data, figures are given for the mean thermal conductivity of insulation materials. These should be compared with the values given in Table 1 for the appropriate insulation, and confirmed with the insulation manufacturers and suppliers.

Fuel Efficiency Booklet 8 - *The Economic Thickness of Insulation for Hot Pipes* - contains a more detailed discussion of the derivation of these tables, and typical methods for calculating the economic thickness of insulation by customised tabulation; it is recommended that it is read in conjunction with this booklet.

Refrigeration applications to prevent condensation

Tables 2 - 5 (Pages 9 to 11) give the minimum thicknesses of insulation to prevent condensation on the outer surface of the insulating material, under the stated conditions of ambient temperature, relative humidity and emissivity of the external surface.

Chilled and cold water supplies to prevent condensation

Tables 6 and 7 (Pages 11 and 12) give the minimum thicknesses of insulation needed to prevent condensation on the outer surface of the insulating material under the stated conditions.

Protection against freezing in industrial applications

Table 8 (Page 12) gives data on the minimum thickness of insulation required to give protection against freezing under industrial conditions. These are for outdoor steel pipes, and the ambient temperature is assumed to be -10°C.

Obviously some of the thicknesses are impractical, and in these circumstances consideration should be given to trace heating (heat applied externally to a pipe in order to maintain its temperature) to supplement a reduced insulation thickness.

Central heating, air-conditioning and direct hot water supply installations in non - domestic applications

Tables 9 - 11 (Pages 13 to 15) give economic thicknesses of insulation for non-domestic heating installations served, respectively, by solid fuel, gas and oil-fired boiler plant.

The cost of heat in these and in subsequent

RECOMMENDED THICKNESSES OF INSULATION

tables in this Section is as follows (from BS 5422: 1990):

Solid fuel: 0.38 p/useful MJ
Gas: 0.57 p/useful MJ
Oil: 0.76 p/useful MJ

A boiler efficiency of 70% is assumed in all cases.

Table 12 (Page 16) gives data on the economic thickness of insulation for hot water services. Costs of heat are as stated above, the data for the three principal fuels being included in the single table.

As well as pipework, ducting should be insulated in appropriate cases. In particular, ducts carrying warm air and those where condensation might occur (where chilled air is being conveyed) are important. Insulation data for these cases are given in Tables 13 and 14 (Pages 16 and 17) respectively. Note that in the case of Table 14, the assumed ambient conditions are a temperature of +25°C and a relative humidity of 80%. The finishes range from highly polished metal (low coefficient) to a painted surface (high coefficient).

Process pipework and equipment applications

Table 15 (Pages 18 and 19) gives data on the economic thicknesses of insulation for process pipework and equipment. The energy cost used is for gas at 0.57 p/MJ. Data are presented for various hot face temperatures from 100°C to 700°C.

Table 2 Minimum thickness of insulation for refrigeration applications to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +20°C and a relative humidity of 70% r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	5	6	7	9	6	9	12	14	9	12	16	19	11	15	20	22	13	18	22	27
33.7	5	7	8	10	7	10	13	16	9	14	17	20	12	16	21	25	13	19	25	30
60.0	5	7	9	11	7	11	13	17	9	14	19	22	12	17	23	28	13	20	27	33
114.3	5	7	9	11	7	11	14	18	10	15	21	25	12	19	26	32	15	23	31	38
168.3	5	7	9	11	7	11	16	20	11	16	22	27	13	21	28	35	17	25	34	42
273.0	5	7	9	12	8	12	17	21	11	18	24	29	15	23	30	38	18	28	37	46
508.0	5	7	10	13	9	14	17	22	12	19	25	32	16	25	32	40	19	29	40	49

RECOMMENDED THICKNESSES OF INSULATION

Table 3 Minimum thickness of insulation for refrigeration applications to prevent condensation on a low emissivity outer surface (0.2) with an ambient temperature of +20°C and a relative humidity of 70% r.h

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	8	10	13	16	12	17	21	26	16	22	29	35	20	28	36	43	24	33	42	51
33.7	9	12	15	18	13	19	24	29	18	25	33	39	22	31	40	49	26	37	48	60
60.0	10	13	17	21	15	22	27	34	20	29	38	46	24	36	48	60	29	43	58	73
114.3	10	15	20	25	17	26	33	42	23	36	48	60	29	46	62	75	37	56	73	88
168.3	11	17	22	28	19	30	40	48	28	41	53	65	36	52	67	80	43	61	79	96
273.0	13	19	25	31	22	32	42	52	30	45	58	70	39	56	72	88	46	67	87	106
508.0	13	20	27	33	23	34	45	55	32	47	62	77	41	61	78	96	49	73	95	116

Table 4 Minimum thickness of insulation for refrigeration applications to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +25°C and a relative humidity of 80% r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	9	12	15	18	12	17	21	25	15	21	27	32	18	25	32	37	21	29	36	43
33.7	10	14	17	21	13	19	24	29	17	24	30	35	20	27	35	42	22	32	41	49
60.0	11	15	19	23	15	21	26	32	18	26	33	40	21	30	39	48	24	35	45	56
114.3	11	16	21	26	15	23	29	36	19	29	38	46	23	35	46	57	28	41	54	66
168.3	11	17	22	27	16	24	32	40	21	31	41	51	26	39	51	61	31	45	59	71
273.0	12	18	23	29	18	26	35	43	23	34	45	55	29	41	54	67	33	49	64	79
508.0	12	19	25	32	19	28	36	45	24	36	48	60	30	45	58	72	35	53	69	85

RECOMMENDED THICKNESSES OF INSULATION

Table 5 Minimum thickness of insulation for refrigeration applications to prevent condensation on a low emissivity outer surface (0.2) with an ambient temperature of +25°C and a relative humidity of 80% r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	17	23	29	36	23	32	41	50	29	41	53	65	35	50	65	81	41	59	77	100
33.7	19	27	33	41	26	37	47	58	33	47	62	76	40	57	76	98	46	68	93	115
60.0	22	31	40	49	30	44	57	72	38	57	77	96	46	70	95	114	54	85	109	130
114.3	25	38	51	65	37	57	73	88	49	92	92	110	61	86	109	131	72	99	125	150
168.3	30	45	57	69	43	62	79	95	55	99	99	119	66	94	119	142	77	108	137	164
273.0	33	48	61	74	47	67	86	104	60	110	110	131	73	102	131	157	84	119	152	182
508.0	34	51	66	81	50	73	94	115	64	121	121	147	78	113	145	176	91	132	169	205

Table 6 Minimum thickness of insulation for chilled and cold water supplies to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +25°C and a relative humidity of 80% r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)											
	+10				+5				+0			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)											
21.3	6	8	9	11	8	9	12	15	9	12	15	18
33.7	6	8	11	13	8	11	14	16	10	14	17	21
60.0	6	9	12	14	9	12	15	18	11	15	19	23
114.3	6	9	12	14	9	13	16	20	11	16	21	26
168.3	6	9	12	15	9	13	17	21	11	17	22	27
273.0	6	9	13	16	9	14	19	22	12	18	23	29
508.0	7	10	13	16	10	14	19	24	12	19	25	32
Flat surfaces	7	10	14	17	10	15	20	25	13	20	26	33

RECOMMENDED THICKNESSES OF INSULATION

Table 7 Minimum thickness of insulation for chilled and cold water supplies to prevent condensation on a high emissivity outer surface (0.2) with an ambient temperature of +25°C and a relative humidity of 80% r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)											
	+10				+5				+0			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)											
21.3	10	14	17	20	14	18	23	28	17	23	29	36
33.7	11	16	20	24	15	21	27	32	19	27	33	41
60.0	13	18	23	28	17	25	31	38	22	31	40	49
114.3	14	20	27	33	20	30	38	48	25	38	51	65
168.3	15	23	31	39	22	35	45	54	30	45	57	69
273.0	17	26	34	42	25	37	48	58	33	48	61	74
508.0	19	28	36	44	27	39	51	63	34	51	66	81
Flat surfaces	21	31	41	52	29	44	58	73	37	56	75	94

Table 8 Calculated minimum thickness of insulation required to give protection against freezing under industrial conditions

Water temperature		+5°C				+5°C			
Ambient temperature		-10°C				-10°C			
Evaluation period		12 h				12 h			
Permitted ice formation		Nil				10%			
Calculation method		H.2.2				H.2.2			
Outside diameter	**Inside diameter (bore)**	**Thermal conductivity (in W/(m.K))**							
		0.02	**0.03**	**0.04**	**0.05**	**0.02**	**0.03**	**0.04**	**0.05**
mm	**mm**	**Thickness of insulation (in mm)**							
Steel pipes									
21.3	16.0	-	-	-	-	1034	-	-	-
26.9	21.6	5028	-	-	-	179	715	2740	-
33.7	27.2	716	4812	-	-	74	195	473	1121
42.4	35.9	203	708	2349	-	37	75	137	240
48.3	41.8	124	340	875	2195	28	51	85	135
60.3	53.0	66	141	275	513	19	32	48	69
76.1	68.8	41	75	123	193	13	21	30	40
88.9	80.8	31	54	84	122	11	17	24	31
114.3	105.3	22	35	51	70	8	12	17	21
168.3	158.6	14	21	29	37	5	8	10	13
219.1	207.9	10	16	21	27	4	6	8	10

RECOMMENDED THICKNESSES OF INSULATION

Table 9 Economic thickness of insulation for non-domestic heating installations served by solid fuel-fired boiler plant

Outside diameter of steel pipe on which insulation thickness has been based (in mm) [1]	Hot face temperature (in°C) (with ambient still air at +20°C)											
	+75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	14	17	20	23	17	21	24	26	22	25	28	32
21.3	15	18	22	24	17	22	25	27	23	26	30	34
26.9	17	20	23	25	20	24	26	28	24	28	32	35
33.7	17	21	24	26	20	25	27	31	25	29	34	37
42.4	18	22	25	27	21	25	28	32	25	31	35	39
48.3	18	23	25	28	22	26	29	33	26	32	36	41
60.3	19	24	26	29	23	27	31	35	27	33	38	43
76.1	20	24	27	31	23	28	33	36	28	35	40	45
88.9	20	24	28	32	24	28	33	37	29	36	42	46
114.3	21	25	29	33	25	30	35	39	30	37	44	48
139.7	22	26	30	34	25	31	36	41	31	38	45	50
168.3	22	26	31	35	25	32	37	42	32	40	46	52
219.1	22	27	32	36	26	33	38	43	33	42	48	54
273.0	23	27	33	36	26	34	39	44	34	43	49	55
Above 323.9 and including flat surfaces	23	28	34	38	27	35	42	47	35	45	53	60

[1] *Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.*

RECOMMENDED THICKNESSES OF INSULATION

Table 10 Economic thickness of insulation for non-domestic heating installations served by gas boiler plant

Outside diameter of steel pipe on which insulation thickness has been based (in mm) [1]	Hot face temperature (in°C) (with ambient still air at +20°C)											
	+75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	17	22	24	26	20	24	27	31	24	29	34	37
21.3	18	23	25	27	22	25	29	33	26	32	36	39
26.9	20	24	26	29	23	27	31	34	27	33	38	42
33.7	21	25	27	31	24	28	33	36	28	35	40	44
42.4	22	25	29	32	25	30	34	38	30	37	42	47
48.3	22	26	30	33	25	31	35	39	31	38	44	48
60.3	23	27	32	35	26	32	37	41	33	39	46	50
76.1	24	28	33	36	27	34	39	43	34	42	48	52
88.9	24	29	34	37	28	35	40	45	35	43	49	53
114.3	25	31	35	39	29	36	42	47	36	45	51	56
139.7	25	32	36	41	30	37	43	48	37	47	53	59
168.3	25	32	37	42	31	38	45	50	38	48	56	61
219.1	26	33	38	44	32	40	46	52	40	51	58	65
273.0	27	34	40	45	33	41	47	53	41	52	59	68
Above 323.9 and including flat surfaces	27	36	42	47	34	43	51	58	42	54	63	72

[1] *Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.*

RECOMMENDED THICKNESSES OF INSULATION

Table 11 Economic thickness of insulation for non-domestic heating installations served by oil-fired plant

Outside diameter of steel pipe on which insulation thickness has been based (in mm) [1]	Hot face temperature (in°C) (with ambient still air at +20°C)											
	+75				+100				+150			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	18	23	25	28	22	26	29	33	26	32	36	40
21.3	19	24	27	29	23	27	32	35	27	34	38	43
26.9	21	25	28	32	24	29	33	36	29	35	41	45
33.7	22	26	29	33	26	31	35	38	31	37	43	47
42.4	23	27	32	35	26	32	37	41	32	39	45	50
48.3	24	28	33	36	27	33	38	42	33	41	46	51
60.3	25	29	34	37	28	35	39	44	35	43	49	52
76.1	25	31	35	39	29	36	42	46	36	45	50	55
88.9	25	32	36	41	30	37	43	48	37	46	51	57
114.3	26	33	38	43	31	38	44	49	39	48	54	60
139.7	27	34	39	44	33	41	47	51	41	50	57	63
168.3	27	35	41	45	33	42	48	54	42	52	59	66
219.1	28	36	42	47	34	43	51	56	43	54	62	69
273.0	29	37	43	48	35	44	52	57	45	55	64	71
Above 323.9 and including flat surfaces	31	38	45	52	37	47	55	62	47	60	69	77

[1] *Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.*

RECOMMENDED THICKNESSES OF INSULATION

Table 12 Economic thickness of insulation for non-domestic hot water services

Outside diameter of steel pipe on which insulation thickness has been based (in mm)[1]	Water temperature +60°C											
	Solid fuel				Gas				Oil			
	Thermal conductivity at mean temperature (in W/(m.K))											
	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07	0.025	0.04	0.055	0.07
	Thickness of insulation (in mm)											
17.2	17	21	24	27	20	24	28	32	22	27	31	34
21.3	18	22	25	28	22	26	30	34	23	28	32	36
26.9	20	23	27	29	23	28	32	35	24	29	34	38
33.7	20	24	28	31	24	29	33	37	26	31	36	40
42.4	21	26	30	33	25	31	34	39	28	33	38	42
48.3	22	27	31	34	26	32	36	40	29	34	39	43
60.3	23	28	32	36	27	33	38	42	30	36	41	45
76.1	23	29	34	37	28	35	40	44	31	37	42	47
88.9	24	30	35	38	29	36	41	45	32	38	44	48
114.3	25	31	36	40	30	37	43	47	33	40	46	51
139.7	25	32	37	41	31	38	44	50	34	41	47	54
168.3	26	33	38	42	32	39	45	52	34	42	51	56
219.1	26	34	39	44	33	41	47	55	35	44	53	59
273.0	27	35	40	45	34	42	51	57	36	45	55	61
Above 323.9 and including flat surfaces	29	36	42	50	35	44	54	61	40	51	59	65

[1] *Outside diameters are as in BS 3600. The same thickness of insulation would be used for copper pipework of approximately similar outside diameters.*

Table 13 Economic thickness of insulation on ductwork carrying warm air

Temperature difference between air inside ductwork and ambient still air (in K)										
+10				+25				+50		
Thermal conductivity at mean temperature (in W/(m.K))										
0.02	0.04	0.055	0.07	0.02	0.04	0.055	0.07	0.04	0.055	0.07
Economic thickness of insulation (in mm)										
25	38	50	50	30	50	50	75	63	75	75

ENERGY AND COST SAVINGS WITH INSULATION

Table 14 Minimum thickness of insulation for condensation control on ductwork carrying chilled air

Minimum air temperature inside duct (in °C)	Thermal conductivity at mean temperature of +10°C (in W/(m.K))											
	0.025			0.035			0.045			0.055		
	Surface coefficient											
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
	Thickness of insulation (in mm)											
15	15	9	6	21	12	9	28	15	11	33	19	13
10	27	13	11	38	21	15	48	27	19	58	32	23
5	38	22	15	53	30	21	68	38	27	82	46	32
0	50	30	19	68	39	27	87	50	38	105	60	42

Note 1: The thicknesses given are for vertical surfaces of ductwork but are also adequate for horizontal surfaces.

Note 2: The surface coefficients for heat gain (in W/m^2) in the calculations were taken to be as follows:
low 2.75;
medium 5.02;
high 7.29.

6 ENERGY AND COST SAVINGS WITH INSULATION - LIMITATIONS OF A SIMPLE ANALYSIS

With present fuel prices and the cost of insulation, any recommended thicknesses calculated on the basis of economics will adequately cover the aspects of surface temperature limits. For example, with a 100°C hot face temperature and 25 mm of calcium silicate on a 150 mm nominal bore pipe, the surface temperature will be about 30°C. At the other end of the temperature scale, for the same pipe with a 700°C hot face temperature and a thickness of 100 mm of calcium silicate, the surface temperature will be about 60°C. Both of these temperatures assume 20°C ambient temperature and a surface of high emissivity.

The condition of the heated fluid can vary greatly at the point of delivery. Excessively long runs of pipework outdoors will deliver working fluids at comparatively lower temperatures and, in the case of steam, in a very wet condition. In these cases, the economic thickness may not be sufficient to meet process requirements and, as recommended earlier, specific checks should be made.

Bearing in mind these provisos, the exercise to select the economic thickness and type of insulation will vary with the particular application.

In the case of pipes at a constant temperature, there will exist a steady state with a corresponding heat loss, and the type of calculation detailed in Fuel Efficiency Booklet 8 - *The Economic Thickness of Insulation for Hot Pipes* - can be used to determine the appropriate standard of insulation.

There are, however, applications where there is no steady state, and other considerations then have to be taken into account. Examples of this type of application are items of process plant which are operating on an intermittent basis, such as furnaces on batch production. In these cases, the determination of the optimum

ENERGY AND COST SAVINGS WITH INSULATION

Table 15 Economic thickness of insulation for process pipework and equipment

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)														
	+100					+200					+300				
	Thermal conductivity at mean temperature (in W/(m.K))														
	0.02	0.03	0.04	0.05	0.06	0.03	0.04	0.05	0.06	0.07	0.03	0.04	0.05	0.06	0.07
	Thickness of insulation (in mm)														
17.2	28	31	35	38	41	45	49	52	56	59	52	57	61	66	70
21.3	29	33	37	40	43	46	50	54	58	62	55	60	65	70	74
26.9	31	35	39	43	46	50	54	59	63	67	59	64	69	74	78
33.7	33	36	40	44	48	52	56	61	65	69	61	66	72	77	82
42.4	36	40	45	49	53	56	61	67	72	77	67	73	79	84	90
48.3	38	42	47	51	55	59	64	70	75	80	70	77	82	88	95
60.3	41	45	50	55	59	63	69	75	81	86	76	82	89	96	102
76.1	42	47	52	57	62	67	73	79	85	90	78	86	94	101	107
88.9	44	49	54	59	64	70	76	82	89	94	83	90	98	105	112
101.6	45	50	56	62	66	73	79	85	91	97	85	93	101	109	116
114.3	46	52	57	63	68	76	80	87	93	99	87	95	103	111	118
139.7	49	54	60	66	71	78	84	92	99	105	94	102	110	118	125
168.3	52	58	64	70	76	83	90	98	105	111	101	107	117	126	134
219.1	54	60	67	74	80	87	95	104	112	119	105	114	124	133	142
244.5	55	62	69	76	82	89	98	106	115	122	108	117	127	137	146
273	56	64	71	78	84	94	100	110	118	126	113	120	132	142	151
323.9	58	66	73	80	86	94	104	114	123	132	115	123	135	145	154
355.6	59	67	74	81	88	97	107	116	125	134	116	125	137	147	156
406.4	62	69	76	83	90	100	109	118	127	136	118	128	140	150	159
457	63	70	77	84	91	102	111	120	129	138	121	132	144	154	163
508	65	72	79	86	93	105	114	123	132	141	124	134	146	156	165
Over 508 and including flat surfaces	72	78	87	98	105	113	124	133	142	151	127	137	151	161	170

ENERGY AND COST SAVINGS WITH INSULATION

Table 15 continued

Outside diameter of steel pipe (in mm)	Hot face temperature at mean temperature (in °C) (with ambient still air at +20°C)																			
	+400					+500					+600					+700				
	Thermal conductivity at mean temperature (in W/(m.K))																			
	0.04	0.05	0.06	0.07	0.08	0.05	0.06	0.07	0.08	0.09	0.06	0.07	0.08	0.09	0.10	0.07	0.08	0.09	0.10	0.11
	Thickness of insulation (in mm) (see note)																			
17.2	64	69	74	79	83	76	81	86	**91**	**95**	89	**93**	**98**	**103**	**107**	**99**	**104**	**109**	**114**	**119**
21.3	68	73	78	83	88	81	86	91	**96**	**101**	93	**98**	**103**	**108**	**113**	**105**	**110**	**115**	**120**	**125**
26.9	73	78	83	89	94	87	92	98	**103**	**107**	100	**105**	**110**	**115**	**120**	**113**	**118**	**123**	**128**	**133**
33.7	76	81	87	92	97	89	95	100	**106**	**111**	103	**108**	**114**	**119**	**124**	**116**	**121**	**127**	**132**	**137**
42.4	83	89	96	102	107	99	105	111	117	**123**	114	**120**	**126**	**132**	**137**	**128**	**134**	**140**	**146**	**152**
48.3	87	93	100	106	112	103	109	116	122	**128**	119	**125**	**132**	**138**	**143**	**134**	**140**	**146**	**152**	**158**
60.3	94	101	108	115	121	111	118	125	132	138	128	135	**142**	**149**	**156**	**144**	**151**	**158**	**165**	**172**
76.1	99	106	114	121	127	117	124	132	139	146	135	142	**149**	**156**	**163**	**152**	**159**	**166**	**173**	**180**
88.9	103	110	118	126	133	123	130	138	145	152	141	148	**156**	**163**	**170**	**159**	**166**	**174**	**181**	**189**
101.6	106	114	123	130	138	126	134	142	150	157	145	153	**161**	**169**	**177**	**164**	**172**	**180**	**187**	**195**
114.3	109	116	125	133	140	129	137	145	153	160	149	157	**165**	**173**	**181**	**167**	**175**	**183**	**191**	**198**
139.7	116	124	133	141	149	138	146	155	163	171	158	167	**175**	**184**	**190**	179	**187**	**195**	**204**	**211**
168.3	124	132	142	151	159	147	156	165	174	182	170	178	188	**196**	**205**	191	**200**	**209**	**218**	**227**
219.1	130	140	151	161	171	156	166	176	186	195	180	190	200	210	**220**	203	**213**	**223**	**233**	**243**
244.5	135	145	156	165	175	161	171	182	192	201	186	196	206	216	**226**	210	**220**	**230**	**240**	**250**
273	139	149	160	170	180	166	176	188	198	207	191	202	213	224	235	217	**227**	**238**	**248**	**258**
323.9	142	153	164	174	184	171	181	193	202	212	196	207	218	229	240	223	**233**	**244**	**254**	**264**
355.6	146	157	168	178	188	177	185	197	206	216	201	212	224	235	245	230	**240**	**251**	**261**	**271**
406.4	149	160	171	181	192	181	189	202	213	223	207	218	230	241	252	234	**245**	**257**	**269**	**279**
457	153	165	176	187	198	187	196	209	220	231	213	225	238	250	261	242	254	**266**	**278**	**289**
508	155	168	179	191	202	191	200	213	226	237	218	231	244	256	267	248	260	**273**	**285**	**296**
Over 508 and including flat surfaces	158	171	182	195	205	194	207	218	230	239	228	240	250	**261**	**270**	**257**	**271**	**279**	**293**	**304**

Note: For thicknesses in bold type, the outside surface temperature is likely to exceed 50°C if a low emissivity surface is used, i.e. bright metal

FINISHES

thickness of insulation, and indeed the type of insulation, becomes a more complicated analysis. Some points which have to be taken into account are described in Section 9.

7 FINISHES

Finishes are applied to insulation to offer protection and support and, to a lesser extent, for aesthetic reasons. The type of finish used depends principally on whether the insulation is to be used indoors, or outdoors where it will be exposed to the elements.

Indoor finishes

Indoor finishes may be divided into the following categories:

- *Hard-setting composition, self-setting cement and gypsum plaster*
  Hard-setting clay-based composition is applied over preformed or plastic insulation on installations where heat is available for drying out. Self-setting cement is a hydraulic setting compound, for use over preformed, plastic or sprayable insulation which can absorb some of the water from the mix. Gypsum plaster is recommended for use on non-absorbent materials such as expanded plastics, cork or resin-bonded mineral wool; the plaster temperature should not exceed 50°C.
- *Textile fabrics*
  Lightweight canvas and bands
  These are pipe sections encased in cotton canvas, which is attached by means of an adhesive and supported by metal bands.
  Heavy fabric wrappings
  These consist of a layer of heavy cotton canvas or, where a non-combustible or rot-proof cover is required, a layer of glass cloth may be applied. They are usually secured by stitching.
- *Plastic and elastomer sheets*
  Plastic sheets may be rigid or flexible.
  Rigid plastics
  These are normally fixed to some framework. Thin sheets with reinforcement may be sufficiently flexible to use in the same way as sheet metal and can be used with flexible insulation.
  Flexible plastics and elastomer sheets
  These are fixed to the insulation with suitable adhesives. It is important that the manufacturer's recommended products are used to ensure satisfactory adhesion. Plastic tape may be used on small diameter pipes; this is normally wrapped around the pipe in a spiral fashion.
- *Mastics and coatings*
  These can be water based emulsions, solvent based or solvent free, and can be sprayed on or applied by hand, depending on the supplier's recommendations concerning safety (e.g. solvent vapours). The surface or ambient temperature at the time of application is important; for best results temperatures below 5°C should be avoided.
- *Aluminium foils and laminates*
  Plain aluminium foil or reinforced foil laminates may be pre-applied to insulation material by the insulation supplier/manufacturer. Further finishing is generally not necessary.
- *Metal sheets*
  Metal sheets provide good protection against mechanical damage and also against the ingress of liquids, such as oil and water.

They can be applied to provide local protection for insulation in particularly vulnerable areas. Mild steel can be used, provided that it is galvanised or coated in some other way to prevent corrosion, and the use of alloy steels may be justified in certain cases. Aluminium is only recommended where it is unlikely to be subject to severe wear and tear, as it is a relatively soft metal and can easily get damaged.

Care should be taken that the metal finish is compatible with the insulant materials with which it comes into contact.

Outdoor finishes

Outdoor finishes, sometimes called weather-resistant finishes, should be able to withstand any outdoor conditions likely to be encountered. Indoor finishes may be used, but additional protection may be required.

- *Hard-setting compositions and self-setting cement*
  Both of these finishes can be protected by weather-resistant finishes. Self-setting cement is not impervious to water, and a water-proofing coat will be required. In the case of some hard-setting compositions, a priming coat is recommended due to their dusty nature.
- *Textile fabrics*
  As these finishes are not impervious to water, they will need protection when used outdoors (e.g. painting).
- *Plastic and elastomer sheets*
  These finishes tend to be weather-resistant, but care is needed to ensure that joints overlap and that they are properly sealed. Good fixing to prevent wind damage is also recommended.
- *Mastics and coatings*
  These finishes are weather-resistant, but care should be taken to ensure that they are stored and installed under the correct conditions.
- *Metal sheets*
  These can be weather-resistant either in themselves (e.g. aluminium) or when suitably treated (e.g. galvanised steel). Electrolytic corrosion can occur, and precautions should be taken to protect against this. The proper positioning and sealing of joints is essential to prevent the ingress of water. Galvanising provides a weather-resistant protection for mild steel, but it is not permanent and its duration will depend on the galvanising method used. Additional painting or another form of protection may be needed after a certain period of exposure. Plastic coated steels and alloys should survive well outdoors.

Summary

The choice of finish depends on two main parameters:

- The type of insulation to be covered The finish should provide sufficient mechanical protection for the insulation, and should be compatible with it.
- The conditions which have to be resisted This will include many aspects, such as weather and extreme temperatures.

8 GENERAL GOOD PRACTICE

There are many practical considerations involved in the planning and implementation of thermal

GENERAL GOOD PRACTICE

insulation. It is preferable to build adequate insulation into plant at the design stage; retrofitted insulation is often less efficient due to space restrictions, lack of support for the insulant and so on.

When to insulate

In general, all hot surfaces above 60°C and most of those above 50°C should be insulated. The insulation of many surfaces below 50°C will often also be justified, particularly from a cost saving point of view. Surfaces include valves and flanges, in addition to pipes and other plant.

Pipes carrying chilled water and other refrigeration services should be insulated to prevent condensation and heat gain.

Application of the insulation

The application of insulation is as important as its thermal properties; incorrect application can reduce the effectiveness of the insulation. It is important when installing insulation to ensure that:

- the insulation will not suffer subsequent damage due to impact, weather or wear. The ability of the insulation type to withstand the conditions in which it will be placed must be considered; finishes which will give added protection may be available (see Section 7).
- surfaces are not left uninsulated just to give convenient access. Removable insulation jackets can be used.
- there are no open joints in the insulation; overlapping of two layer insulation should be carried out if necessary.
- heat losses by conduction to supports are eliminated as far as possible. The use of insulated pipe supports should be considered.
- proper on-site supervision is provided; for example, by using specialised insulation contractors. Insulation is often not as efficient as it could be because it has been applied under poor conditions. If insulation is stored prior to application, care must be taken to avoid physical or weather damage.
- as much work as possible is done off site prior to delivery so that installation times can be minimised and the risks involved can be reduced.

Safety aspects

There are many safety factors which must be considered when applying thermal insulation. In all cases where operator/fire safety has to be taken into account, reference should be made to the appropriate health and safety legislation, and to the instructions of the insulation manufacturers.

Where it is not possible to protect surfaces from direct contact, effective guards should be installed, such as wire mesh screens.

Certain finishing cements are strongly alkaline when wet and may cause skin irritation; gloves should be worn when handling these materials. Additionally, chemical fuming can occur from *in situ* foaming or spraying of organic insulating materials, and personnel should be provided with suitable respirators.

General considerations

It is essential that thermal insulation for plant and equipment is considered early in the design stage, such that an insulation contractor can submit a suitable system that can be incorporated by the plant designer. In retrofit situations, insulation

has to be built around the existing plant design and the best solution may not be feasible.

Items that should be considered during design include allowing sufficient clearance around pipes and equipment to fit adequate insulation, and allowing for the additional weight of the finished insulation system.

The technical suitability of an insulation system is of primary importance, although availability, service and cost should also be taken into account.

9 INSULATION OF PLANT AND EQUIPMENT

Boiler plant

The insulation of boiler plant is normally carried out perfectly adequately by the boiler manufacturer, either at the manufacturer's works or during installation on site. The insulation will generally take two forms:

- mineral fibre slabs fixed to the outer surface of the boiler shell, with an appropriate finish, to inhibit heat losses from the working medium of steam, water or thermal fluid. On older boiler plant the mineral insulation may be damaged, and this should be replaced when necessary, together with the finish, to ensure continued efficient insulation.
- other insulation applied to air-exposed surfaces containing hot gases. For example, combustion chambers and flues.

Pipes

Pipe insulation is probably the most common form of insulation used in industry. Preformed insulation sections are available, making installation much easier. Insulation thickness data are given in this booklet for typical fuel prices and installation costs (see Section 5), but these may vary with situation and it is recommended that cases are individually assessed.

It is important that attention is also paid to insulating flanges and valves. Preformed, easily removable insulation sections tailored to these items of pipework fittings are available. Whilst ideally the thicknesses of insulation on flanges and valves should be the same as that on the adjoining pipe, this may be impractical due to space and other limitations.

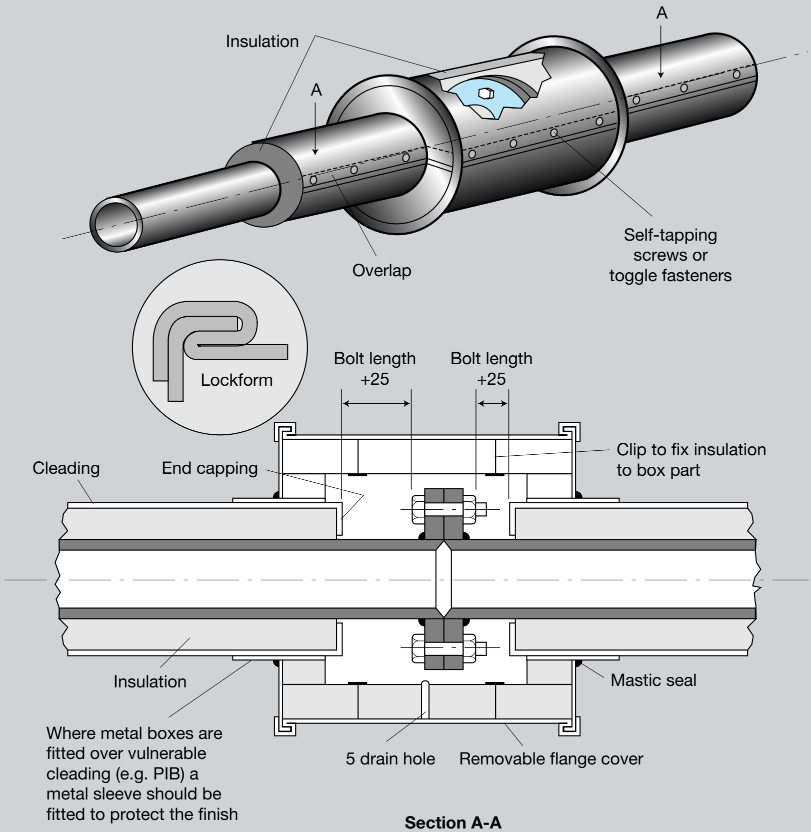
As an indication of the scale of heat loss from flanges and valves, an uninsulated valve would lose heat equivalent to a 1 m length of uninsulated pipe, and an uninsulated flange will lose half this value. A typical method for insulating a flange is shown in Fig 1.

As mentioned in previous Sections, the pipes can also lose heat through their supports, and these should be insulated. Recommended methods are shown in Figs 2, 3 and 4.

The problems associated with pipes carrying liquid in low ambient temperatures and at low flow rates have been discussed in Sections 2 and 5. It is recommended that trace heating is used in such circumstances. A similar need for trace heating arises in the case of heavy fuel oil for boilers, which can become highly viscous at low temperatures, affecting its ability to be pumped. When the boiler is firing, the outflow or line heater should be sufficient to bring the oil to pumping temperature; however, the use of trace heating in the first stage is normally required. A typical method of insulating steam traced pipes is shown in Fig 5.

INSULATION OF PLANT AND EQUIPMENT

Fig 1 Method for insulating pipe flanges (hot insulation)



All dimensions shown are in millimetres.

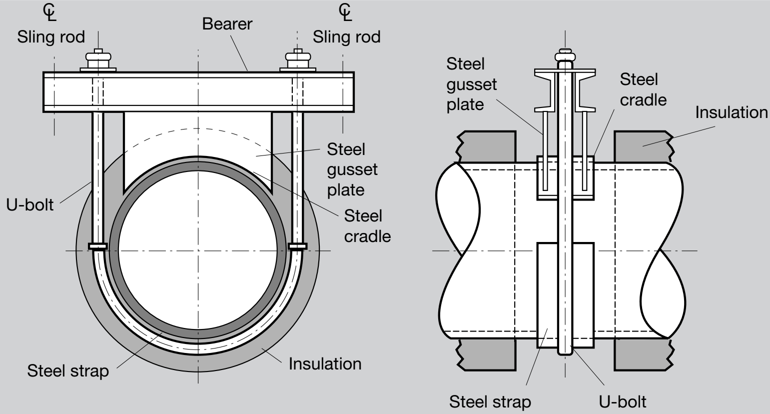
Note: Insulation to be fixed to box parts for easy removal and replacement of the assembly

It is important to remember that insulation may need supporting. Vertical piping will need additional supports for insulation above bends, flanges and valves. In the case of flanges and valves, supports must be positioned to allow easy access for maintenance. The supports should be welded to the pipe and can be either bars, angles or studs of sufficient length to reach 15 mm below the surface of the insulation.

When insulation exceeds 65 mm thickness, two layers will often be used. In all cases of multi-layer insulation, joints should be staggered so that

INSULATION OF PLANT AND EQUIPMENT

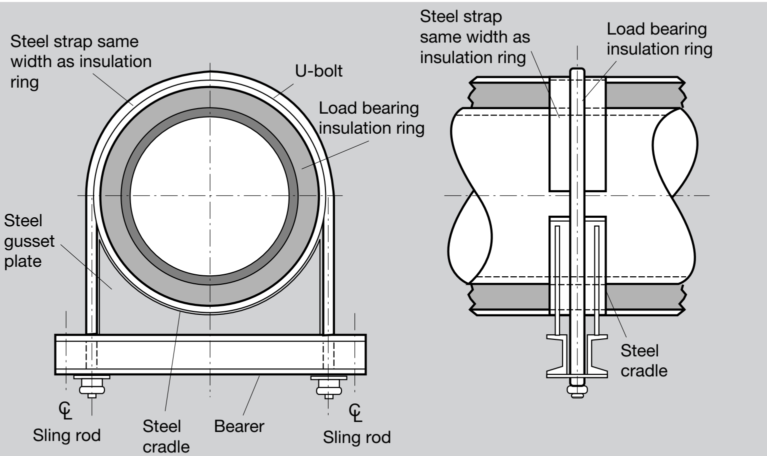
Fig 2 Inverted U-bolt cradle, direct contact



there are no open joints. A typical method of staggering is shown in Fig 6. Expansion joints may be needed at intervals that vary with the operating temperature to ensure consistent insulation over the whole temperature range.

Where the temperature or other conditions at the point of delivery of the fluid are important, selection of the insulation thickness should take into account adverse weather conditions (e.g. wind, rain etc.), low ambient temperatures and low flow rates of the fluid. Examples of the effect of wind speed on pipe insulation are given in Fuel Efficiency Booklet 8 - *The Economic Thickness of Insulation for Hot Pipes.*

Fig 3 U-bolt cradle using insulation ring



INSULATION OF PLANT AND EQUIPMENT

Fig 4 Two-piece strap, using insulation ring.

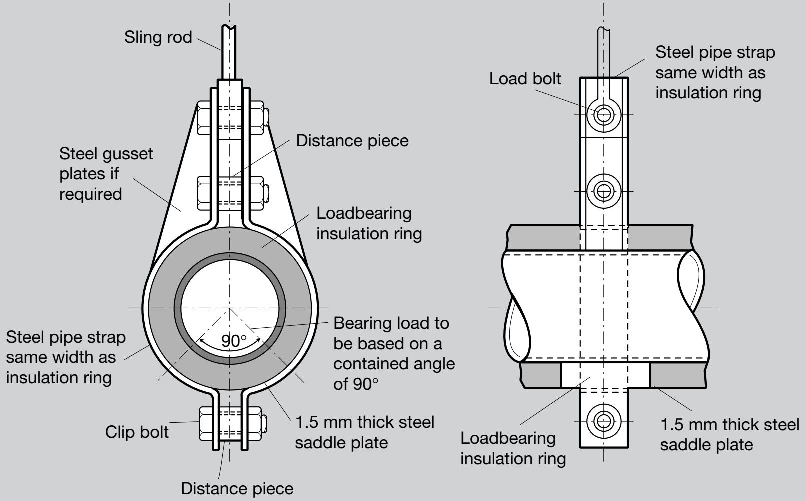
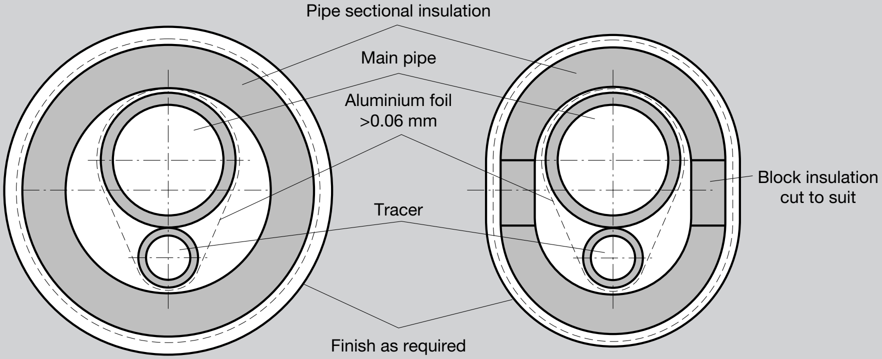


Fig 5 Typical method of insulating steam traced pipes



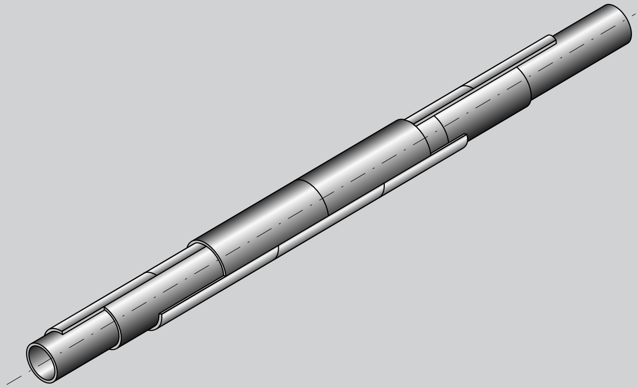
Finishes have already been discussed in Section 7. It cannot be emphasised enough that insulation finishes should be suitable for their environment. Good insulation can be ruined by the ingress of water or chemicals.

Vessels and large curved surfaces

When insulating vessels, the need to dismantle associated pipework and remove inspection covers should be anticipated. Permanent insulation should end sufficiently far away from

INSULATION OF PLANT AND EQUIPMENT

Fig 6 Typical method of staggering insulation sections on a straight pipe



Note: Binding wire or bands on each layer of insulation spaced at intervals of 450 mm (maximum) and not less than 50 mm from the end of each section.

flanges and fittings to enable bolts to be withdrawn, with removable sections used to complete the insulating layer. For external applications or where fluid spillages can occur, the permanent insulation should have a suitable finish to prevent fluid ingress when removable sections are not in place.

Special consideration should be given to the support of insulation for vessels and columns subject to wind loads.

The level of insulation selected may well be based on safety, from the point of view of surface temperature, rather than economics because the thickness calculations are more complicated than in the case of pipes. The large number of sizes and shapes of vessels means that most insulation will be made to measure. Some typical methods of applying insulation to vessels are shown in Figs 7 and 8.

Where a vessel containing a hot liquid has an open top, additional heat loss can occur by evaporation. This loss can be minimised by adding a blanket of commercially available floating plastic balls to the surface of the liquid . For example, a single layer of balls which covers 91% of the surface of the liquid, would reduce the energy input required to maintain the tank liquid at 90°C by 70%. The use of these balls can also reduce ventilation requirements, resulting in further energy savings.

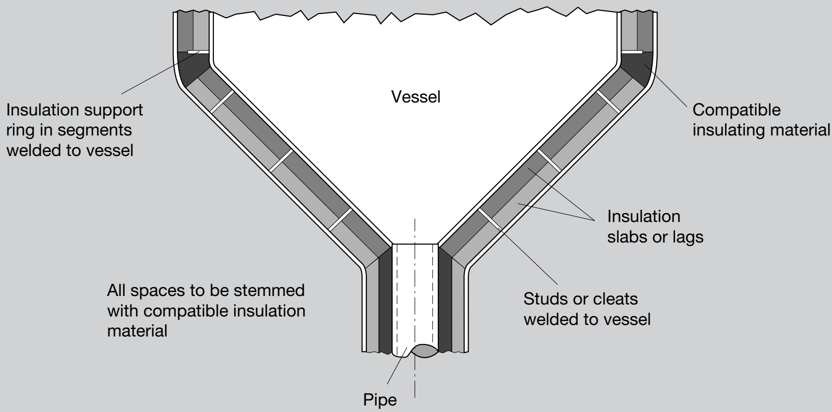
Hot gas ducts and flues

The insulation of hot gas ducts and flues may be carried out for two main reasons:

- for safety, because of the high external temperatures;
- to prevent internal condensation, normally caused when internal surfaces fall to a temperature below the dewpoint of the gases being conveyed. Condensation can lead to corrosion, particularly in the exhaust ducts of oil-fired boiler plant where the flue gases

INSULATION OF PLANT AND EQUIPMENT

Fig 7 Typical method for insulating vessels with conical bottoms



are acidic. It is important to ensure that there is no 'bridging' in the insulation, which could result in local cold spots. Care should also be taken at access points for temperature and sampling probes, and any expansion joints should be adequately insulated to prevent corrosion.

The insulation used on ducts and flues can normally be of the low density type, such as low density mineral fibres, but materials such as calcium silicate or high density mineral fibres should be used where heavy wear or loading is anticipated.

Furnaces and kilns

The insulation of furnaces and kilns is more complex than that for normal items of plant with hot surfaces. There are two main methods of insulation, depending on the operation of the furnace or kiln:

- With continuously operating furnaces, or when internal temperatures and atmospheres are severe, the inner surface may be a dense refractory with the insulation placed outside it.
- In less arduous conditions and where the furnace is run in a batch mode, the insulation itself may constitute the lining.

Whichever method of insulation is used, heat losses affected by insulation are:

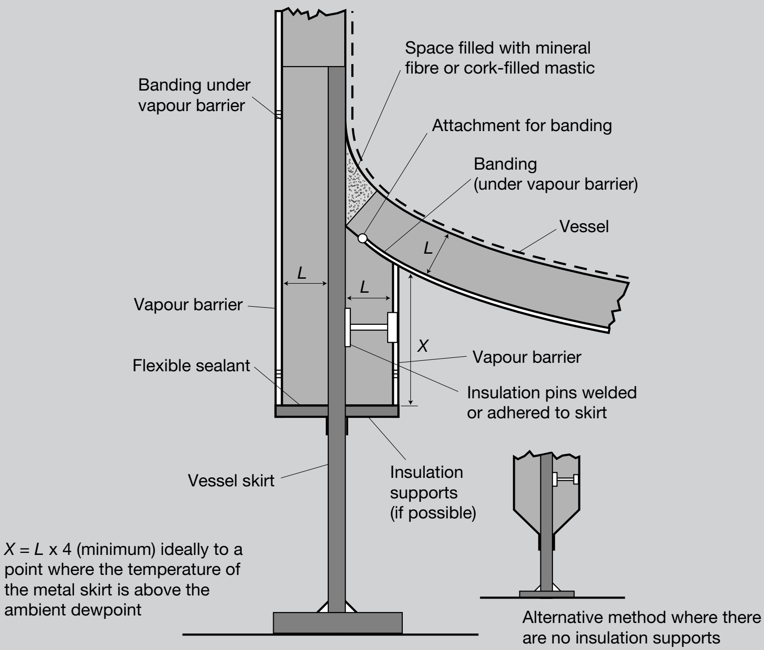
- the loss through the furnace walls due to conduction, convection and radiation;
- the loss due to the thermal mass of the furnace.

These losses can be minimised by proper insulation.

There is a marked difference between the two types of furnace operation. In continuously operated furnaces, the heat loss through the walls at full working temperature is much greater than the energy required to heat up the mass of the furnace. In batch operated furnaces, the loss of heat stored in the mass of the furnace can be greater. Thus in continuously operated furnaces

INSULATION OF PLANT AND EQUIPMENT

Fig 8 Typical method of insulating vessel skirt (cold insulation)



insulation is required to prevent heat loss through the walls and roof, while in intermittently operated furnaces it is required to reduce the heat storage loss without neglecting the external surface losses.

For example, a continuously operated brick walled furnace with walls of nominal thickness 230 mm and an internal wall temperature of 1100°C will lose 5.3 kW/m^2. With a nominal 100 mm of insulation, the heat loss will be reduced to 1.2 kW/m^2, and at 200 mm insulation the loss drops to 660 W/m^2. Heat losses could be reduced by increasing the thickness of the refractory brick lining, but it is more cost-effective to use insulation.

The insulation of furnaces requires careful consideration of the changes in temperature that may occur during operations. Intermittently operated furnaces which need to be cooled substantially as part of the process, will lose their heat much more slowly if externally insulated. Rapid cooling can be effected by drawing volumes of cold air or gas through the chamber, provided that good quality non-spalling brickwork forms the internal surface of the furnace.

The effect of insulation on refractory temperature should also be taken into account.

SOURCES OF FURTHER INFORMATION

The temperature gradient in the refractory is affected, which may lead to overheating of it or of the insulation, and possibly structural failure.

As an example, for the continuously operated furnace quoted above, the effect of insulation would be as follows: with no insulation the refractory external temperature would be 260°C; with a nominal 100 mm insulation it would be 900°C; and with a nominal 200 mm insulation it would reach 985°C. Although a refractory built into a wall or roof can be operated with its face at a temperature above the safe level, as long as the bulk of the brick is at a temperature low enough to withstand the conditions, reducing the temperature gradient over the thickness of the brick by applying external insulation could have serious consequences. For this reason it is recommended that the furnace builder or supplier of the refractory should be consulted before any insulating work is undertaken.

The energy used in heating up a furnace varies according to the nature of furnace operation. While it will be relatively insignificant for a continuously operated furnace once it is at operating temperature, heating the furnace mass and stock on batch operation, particularly on short cycle times, will account for a large proportion of the total energy use. Intermittent operation thus has a marked effect on the relative value of the steady state heat loss and on the amount of energy needed to raise the furnace temperature to the operating level. For example, with a 230 mm wall and 100 mm of insulation, the heat absorbed by the wall in raising it to the working temperature will be equivalent to more than 100 hours of heat loss at steady state.

External insulation on a furnace increases the heat storage capacity of the walls by increasing their average temperature. A 100 mm layer of external insulation will increase the heat stored by about 60%. This is not the ideal solution for saving energy in intermittent furnace operation. It is preferable to reduce the mass of refractory to a minimum using hot face insulation, which may take the form of low density ceramic fibre or microporous insulation. These latter materials are ideal for use in intermittent furnaces, because they have a low thermal mass, low thermal conductivity and are highly resistant to thermal shock. Where additional strength or resistance to the internal environment is required, the insulation may be finished with a suitable coating.

10 ACKNOWLEDGEMENT

The Department of the Environment is grateful to the British Standards Institution for permission to reproduce material from BS 5442: 1990.

11 SOURCES OF FURTHER INFORMATION

■ *British Standards:*

The following British Standards contain further information on thermal insulation, its specification and sources of supply:

BS 5422:1990
Method for specifying thermal insulating materials on pipes, ductwork and equipment (in the temperature range -40°C to +700°C)

BS 5970:1992
Code of practice for thermal insulation of pipework and equipment (in the temperature range -100°C to +870°C)

SOURCES OF FURTHER INFORMATION

Copies of these British Standards are available from:

British Standards Institution
Sales Department
Linford Wood
Milton Keynes
MK14 6LE

- *Insulation Suppliers:*
  TIMSA Handbook:
  The Specifiers Insulation Guide 1992

Copies of this publication are available from:

Thermal Insulation Manufacturers and Suppliers Association
PO Box 111
Aldershot
Hampshire
GU11 1YW
Tel: 01252 336318

- *Energy Efficiency Best Practice programme publications:*

Copies of publications applicable to insulation and to energy efficiency in industry in general are available from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxon
OX11 0RA
Tel: 01235 436747
Fax: 01235 433066

Information is also available through regional Government Offices.

- *The latest news in energy efficiency technology: Energy Management* is a free journal issued on behalf of the DOE which contains information on the latest developments in energy efficiency, and details of forthcoming events designed to promote their implementation. It also contains information, addresses and contacts for the regional Government Offices.

Copies of *Energy Management* can be obtained through:

Emap Maclaren Limited
Maclaren House
19 Scarbrook Road
Croydon
Surrey CR9 1QH

Titles in the Fuel Efficiency Booklet series are:

1 *Energy audits for industry*
1B *Energy audits for buildings*
2 *Steam*
3 *Economic use of fired space heaters for industry and commerce*
4 *Compressed air and energy use*
7 *Degree days*
8 *The economic thickness of insulation for hot pipes*
9 *Economic use of electricity in industry*
9B *Economic use of electricity in buildings*
10 *Controls and energy savings*
11 *The economic use of refrigeration plant*
12 *Energy management and good lighting practices*
13 *Waste avoidance methods*
14 *Economic use of oil-fired boiler plant*
15 *Economic use of gas-fired boiler plant*
16 *Economic thickness of insulation for existing industrial buildings*
17 *Economic use of coal-fired boiler plant*
19 *Process plant insulation and fuel efficiency*
20 *Energy efficiency in road transport*

Fuel Efficiency booklets are part of the Energy Efficiency Best Practice programme, an initiative aimed at advancing and promoting ways of improving the efficiency with which energy is used in the UK.

For copies of Fuel Efficiency booklets or further information please contact the addresses below.

Overseas customers please remit £3 per copy (minimum of £6) to the ETSU or BRECSU address with order to cover cost of packaging and posting. Please make cheques, drafts or money orders payable to ETSU or BRECSU, as appropriate.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related publications please contact:
Enquiries Bureau
BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport publications please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Fax01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.